IMPACTS OF SELECTIVE CATALYTIC REDUCTION ON UTILITY SIZED BOILER SYSTEMS

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ABSTRACT

Today's coal fired steam generators, especially those in the Northeast, are being required to significantly reduce the NOx emissions to the atmosphere. The retrofitting of Selective Catalytic Reduction systems to these steam generators can affect the entire boiler, indeed, the entire site. Presented within are the aspects of such a retrofit, particularly for units that fire medium to high sulfur coal.

INTRODUCTION

The US Environmental Protection Agency has identified areas of serious ozone pollution requiring substantial reductions in low atmospheric NOx, an ozone precursor. Although individual states are required to submit State Implementation Plans (SIP) to address NOx reduction targets, many utilities have already begun developing and implementing plans of their own. The basic system wide NOx target is approximately 0.15 lbs NOx/10^6 BTU. Because some units are not as easily or cost effectively retrofitted with NOx reduction systems, NOx for other units can be reduced further. These reductions can then be used as offsets or to generate credits which may be sold.

There are many possible systems. At a minimum, an overall NOx reduction strategy should consider: Combustion Tuning, Low NOx Burners, Overfire Air Systems, Pulverizer Upgrades including Dynamic Classifiers, Reburn of natural gas or micronized coal, Neural Networks, Selective Non-Catalytic Reduction, Selective Catalytic Reduction and Seasonality. (Foster Wheeler offers a total NOx reduction review program that includes all of the above).

This paper has as its premise that at least some boilers will necessitate significant NOx reduction, requiring the use of Selective Catalytic Reduction (SCR).

PLANNING

The planning of the SCR system can be a considerable task, as nearly every unit configuration is unique. Several iterations may be required to establish the optimum combination of equipment, location and process considerations; i.e., added pressure drop, reagent handling, etc. A full understanding of the system and impacts is essential for a successful SCR system.

SCR CONCEPT

The term Selective Catalytic Reduction (SCR) refers to a process that "reduces" NOx in the chemical sense; the result is taking oxygen from the NOx compounds. It is "selective" in that it that it takes the oxygen only from the

NOx compounds, not carbon compounds, sulfur compounds or other oxygenated compounds. The reduction process in its simplest form is injecting an ammonia-based reagent into the flue gas stream to react with the NOx compounds. This reaction can proceed without aid provided that the temperature in the reaction environment is within the range 1,500° - 2,100° F. Unfortunately, this temperature window does not usually offer adequate residence time, is not easily defined and "moves" in a modulating system. Balanced reagent injection is complicated and unreliable. Therefore, an in-line catalyst bed or reactor is added to form a SCR. The SCR operates at a much lower temperature, in the neighborhood of 600°-750° F typically found between the economizer and air preheater.

The reactor inlet / outlet NOx, yield the total NOx reduction. A one-to-one molar correspondence of NH_3 to NOx reduced establishes the required ammonia injection rate for a given NOx reduction (<90%).

SCR REACTIONS

The major NOx reduction reactions are well known:

$$4NO + 4NH_3 + O_2 \xrightarrow{\text{Catalyst}} 4N_2 + 6H_2O \qquad (1)$$

$$2NO_2 + 4NH_3 + O_2 \xrightarrow{\text{Catalyst}} 3N_2 + 6H_2O \qquad (2)$$

where reaction (1) predominates for fossil fuel firing.

The oxidation reactions are:

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O \qquad +950^{o}F \quad (3)$$

$$2SO_2 + O_2 \xrightarrow{\text{catalyst}} 2SO_3 \qquad (4)$$

Sulfate and Bisulfate reactions:

$$SO_3 + 2NH_3 + H_2O \rightarrow (NH_4)_2SO_4 \qquad (5)$$

$$SO_3 + NH_3 + H_2O \rightarrow NH_4HSO_4 \qquad (6)$$

Dust Collection

The existing method of dust collection impacts on the SCR catalyst configuration. This is simply a result of catalyst exposure to the dust laden flue gases.

Typically, cold end dust collection means exposing the catalyst to a high dust atmosphere. The high dust loading requires somewhat larger catalyst openings or pitch and a resulting larger overall volume. The large particles, however, tend to have a cleaning effect on the catalyst and air preheater surfaces. This scouring effect may reduce the plugging potential from deposits (ammonium bisulfate formation).

A hot side collection system may result in a lower dust loading and finer particulate. This may allow a smaller catalyst pitch and smaller overall volume. The smaller pitch packs more specific surface and therefore requires less total catalyst volume. This saves not only on catalyst but also reactor size and weight, potentially allowing smaller flues, saving on steel and foundations.

Surprisingly, it appears that more frequent sootblowing is necessary for the smaller low dust collection configuration. This has raised some concerns about smaller particles irreversibly plugging catalyst pores, leading some catalyst suppliers to redesign the physical structure for smaller pores in low dust applications.

The designer must also consider flyash collection at turns, probably requiring hoppers. For high dust configurations this will require modifications to the plant's ash handling system. For low dust configurations it may be possible to allow the smaller quantity of ash to build up in the hoppers and empty them during outages.

Space

Generally in SCR retrofits applications, space will be at a premium. Space must be available for the reactor, the interconnecting fluework, support steel and its foundations. Additional space is required for the reagent storage, the CEMS building(s) and other ancillary equipment.

First and foremost, the designer needs to establish the size of the reactor. A rough estimate can be initially determined using the total flue gas flow rate. The cross section of the SCR reactor is designed to sustain a full load gas velocity of 16 -18 fps. Multiply the catalyst [1]space velocity (2,000 - 3,000 1/hr) by the flue gas flow rate (scfh) to estimate the overall catalyst volume and thus the depth. Catalyst supplier(s) can be requested to assist. Usually this results in a two to three catalyst layer design based upon 3' to 3½' layer depth. Space for at least one spare layer should be provided for catalyst management. Additional spare layers make the design more forgiving. Overall depth must include space for the catalyst support structure and sootblowers resulting in about 10' of reactor height for each catalyst layer. The reactor must be placed within the system- including connecting flues, an SCR bypass for seasonality, an economizer bypass for low load operation and all the required support steel and foundations.

[1]Space velocity ˆ Gas Flowrate/Catalyst Volume

Ammonia storage space and location can only be determined after the type of ammonia, anhydrous or aqueous, is established. Anhydrous is nearly pure and so requires less storage volume. However, permitting this type of ammonia in populated areas may be difficult. Aqueous ammonia is diluted with 70 to 80 percent water and therefore requires a substantially larger tank per amount of reagent. However, aqueous ammonia is not subject to strict regulations regarding tank location (see Table 1).

Reliability of deliveries must be evaluated to determine total on-site inventory. The type of delivery vehicle should be considered for siting. For large deliveries, railcars may be preferred, locating the ammonia storage area near a railroad siding.

Trucks carry about 6,000 gallons while railcars carry about 30,000 gallons.

CATALYST

Catalyst elements are supplied as a honeycomb, plate or fiber design. (Fiber catalyst has characteristics similar to both honeycomb and plate designs but on a fiberous strata. Fiber catalysts are typically lighter than others). Pellet designs are somewhat archaic and not recommended. The differences in catalysts are more in pitch and configuration than formulation. Typically, the involved reactive components are WO_3, MnO_2 and V_2O_5 in a TiO_2 base. The V_2O_5 is the most reactive ingredient but it is also responsible for the oxidation of SO_2 to SO_3. Formulations are ultimately determined by the catalyst vendor and based upon the flue gas compositions.

These catalyst materials are not currently listed as hazardous materials for waste disposal (except in California at certain levels). However, it is ***highly*** recommended to return spent catalyst to the supplier for proper recycle or disposal as part of a catalyst management plan. This requirement should be included with the catalyst purchase.

Catalyst Pitch is a description of the catalyst openings. Larger pitch is associated with a large ash size or loading. Pitch does not reflect total open area. In the past, the standard pitch for coal was ~7.5mm for honeycomb and ~6.0 mm (hydraulic diameter) for plate and fiber. As more experience is gained, competition has driven manufacturers to reduce the pitch to increase specific surface area thus minimizing overall required volume. Suppliers should be challenged to substantiate the pitch for the given SCR conditions as the owner will have to operate with the results for a very long period and catalyst plugging must be avoided.

FUEL

Major Constituents Sulfur Compounds

Much has been written about the impact of coal constituents upon the operation of the SCR and its catalyst. By far, the most prevalent and vexatious constituent is sulfur. SO_3 reacting with NH_3 forms $(NH_4)_2SO_4$, a sticky substance that precipitates at lower temperatures (dependent upon concentrations). To avoid catalyst plugging, a minimum SCR temperature should be established. For lower load operation, an economizer bypass can be installed to boost the flue gas temperature. Air preheaters cannot avoid this temperature range, so pluggage must be minimized by minimizing slip and SO_3 concentration. Initial precipitation appears to occur mostly on cracks and joints, so the designer should consider long, closed enameled elements in the bisulfate formation zone and not less than low alloy corrosion resistant material in the hotter sections.

Trace Elements As, Ca, V

Trace elements are a concern both as SCR catalyst poisons and as a combination of these elements in a given fuel specification. Arsenic is perhaps the most common catalyst poison. Most catalyst suppliers recognize that calcium can mitigate the effect of arsenic, but the predictability is still indefinite. It is clear, however, that if calcium is reduced to low enough values, even normally low arsenic content can become a poisoning problem. To this end, some European units have even begun to add limestone to their fuel.

To avoid catalyst poisoning, designers have been requesting the catalyst supplier to detail the acceptable range of coal constituents for future fuel purchases. This method at least alerts the fuel buyer to potential problems and hopefully better choices of supply.

Once poisoned, catalyst loses activity. If the NOx outlet rises above the setpoint, the control system will increase ammonia injection leading to increased slip and subsequent air preheater pluggage.

Of particular significance to heavy oil firing is vanadium content. Because vanadium is a key component in the catalyst, the catalyst activity can actually rise when firing <u>any</u> high V fuel, precipitating the ***removal*** of some of the original catalyst charge to control the SO_2 **û** SO_3 conversion.

CONTROL

SCR control typically requires two basic loops, the ammonia injection control and the economizer bypass control. Sootblower control is generally integrated into the existing sootblower control center.

The ammonia injection is a relatively simple feed-forward feed-back algorithm. The total NOx flow is calculated using the firing rate, excess air or O_2 (total gas flow) and inlet NOx concentration. Typically, a one-to-one correlation of NOx to NH_3 is used to establish the NH_3 flow. The outlet NOx is then measured as a feedback trim. Usually inlet and outlet NOx analyzers are added and existing O_2 analyzers at the economizer outlet are reused.

NH_3 analyzers have been somewhat unreliable for coal firing and so are used for indication only.

The economizer bypass control is setup to maintain a minimum temperature in the catalyst, particularly at low loads. Bypass control is often not straight forward, as the bypass may also affect superheat and reheat sections. Sufficient thermal head may not be available and in this case, a second control damper on the economizer outlet may need to be considered. The impact on turbine efficiency, the cost of the flue duct and added control dampers should be weighed against the potential efficiency loss of raising the minimum SCR operating load. An alternative to an economizer bypass is to shut off the ammonia if operating in this mode is permissible.

In general, the control of the SCR requires expansion of the existing distributed control system (DCS) or separate controllers. Expansion of the DCS is usually preferred as this puts all the information from the boiler at the disposal of the operator and all the SCR parameters in the main console.

STEEL/FOUNDATIONS

The support structure design approach should consider both support by the existing structure and new steel independent of the existing steel. For retrofit situations, space and configuration limitations may require a combination. The original steel designer is often utilized as they hopefully have the design and all the original calculations.

Foundations must be considered in conjunction with the support structure. Because reactor placement is often in the midst of boiler back end equipment, existing foundations must be evaluated and often modified. Perhaps the most common problem is determining underground utilities or other impediments that may be below grade. Again, having the original plans is critically important.

Foundations are also necessary for the ammonia storage and supply system, but generally do not pose a serious obstacle. Location is flexible and can be relatively remote. This area is usually not close to other equipment for safety reasons and is normally mounted on a simple pad.

OPERATING PROCEDURES

SCR additions introduce a number of operational procedures not previously required for a typical utility unit.

Air Heater Washing

Proper air preheater design will allow on-line air preheater blowing with washing during normal annual outages. This maintenance will be required. Additional air preheater off-line washing may come about by improper air preheater element staging, selection of material and flow path configuration; an increase in SO_3 due to a high oxidation catalyst selection; aging SCR catalyst or poor ammonia slip control.

Catalyst Management

A Catalyst management program should be used to maintain activity levels and minimize cost to the operator. The strategy is based upon the idea that when catalyst activity decreases below required levels, its life is not exhausted. Instead, a partial layer of fresh catalyst is added to boost the ***overall*** activity back above required levels.

To facilitate such a management program, the reactor is designed with a spare level, unused by the original catalyst charge. Note that over time, the spare level becomes full, therefore, the system must be designed for access and to accommodate the extra weight and draft loss.

Test coupons provided by the catalyst supplier are tested at predetermined intervals. Based upon these coupon tests, additional or replacement catalyst scheduling is established.

Design Considerations

Proper NH_3 slip is extremely important. Several early units were designed to operate above 5 ppm NH_3 slip, but this proved too high as deposits formed too quickly. Today, most slips are specified around 2 - 3 ppm at actual O_2. To lower the slip, the catalyst volume must be increased to attain the higher catalyst reactivity. Also, static mixers have become more common to achieve a more homogeneous mix, thus a more efficient use of the catalyst.

SCR Bypass - Shutdowns & Seasonality

One significant threat to the catalyst performance is shutdown frequency. Operational experience has shown that frequent shutdowns result in potential moisture buildup on the catalyst, which may enable a number of damaging reactions with components of flyash residue. These reactions include acid corrosion, salt deposition and contaminant infiltration. To minimize exposure, frequent shutdowns should be avoided. For prolonged shutdowns such as seasonality, measures should be taken to avoid moisture deposition on the catalyst.

If inspection of the SCR reactor and catalyst is planned when the SCR is isolated, the isolation must be effective to prevent flue gas infiltration: Double damper arrangements with seal air for safety.

PERFORMANCE IMPACTS

The SCR does not provide any performance gain to the boiler operation. Indeed, the SCR results in added pressure drop, parasitic demands for ammonia vaporization and dilution air supply, increased maintenance and possible loss of efficiency at low loads.

Economizer/Reheater Bypass

Economizer bypass operation usually results in some losses in the economizer which are only partially recovered in the APH.

Some boilers utilize a split flow design for reheat and superheat steam such that it may be required to consider bypass limits to protect minimum reheat temperature.

Increased)P

A significant pressure drop must be expected with an SCR system with probably less than half attributed to the catalyst and the rest to added flues and related components. This impacts the induced draft fan in particular. Because many fans have margin, an attempt to limit this additional pressure drop to within that capacity might be made.

In most cases, however, there are more serious problems, particularly on retrofit units where existing induced draft fans cannot absorb the additional load. Modifications such as larger motors, fan tipping, or even fan replacement may be required. In a recent FW project, the pressure drop increase required the induced draft fan motor horsepower to increase over 30%. In addition, the power distribution system had been saturated with other requirements over the years and it too required substantial upgrading.

Most SCR components affect each other as well as the boiler performance. An adequate understanding of these relationships is necessary for proper design decisions, especially in a retrofit situation.

It is understood that the purpose of an SCR system is environmental. Positive performance and operational gains should be viewed as accruing atmospheric benefits for everyone.

TABLE 1
MINIMUM DISTANCES FOR LOCATION OF AMMONIA STORAGE CONTAINERS

Nominal Capacity of Container (Gallons)	Minimum Dis
	Line of Adjoining Prope which may be built up Highways & Mainline Railroad
*Over 500 to 2000 gals	25 ft
Over 2000 to 30,000 gals	50 ft
Over 30,000 to 100,00 gals	50 ft
Over 100,000 gals	50 ft

Source: ANSI K61.1

CONCLUSIONS

SCR systems in the US often fire coal with higher impurity levels and tend toward more cyclic operation than our European and

Japanese counterparts. Thus, domestic experience is invaluable for determining the proper design margins and operating procedures necessary for a successful installation.

Finally, for the benefit of all, it behooves the industry to share its SCR experience.